Finally, we compare the number of required APs to achieve blockage-free conditions with the SES algorithm and the optimal solution. Since it is too time consuming to get optimal results with a large number of obstacles, here we considered cases with a few obstacles, and then evaluated the average number of APs to achieve full coverage. Fig. 21 shows that the number of required APs with SES algorithm is close to optimal, and as the obstacle scale increases, the gap between SES and optimal becomes smaller, which validates the performance of the SES algorithm.

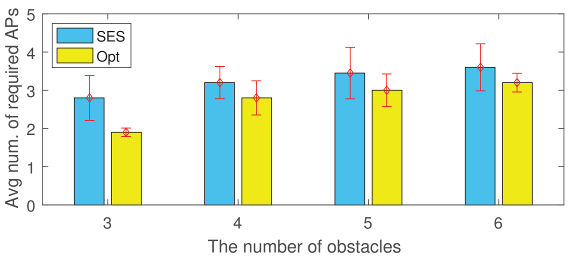

Figure 21: Avg. no. of required APs vs. no. of obstacles.

6 DISCUSSION

Our results can be directly used in practice for network deployment in several ways. If APs are pre-deployed before a room is furnished, or if it is expected that furniture will be moved frequently and moving AP locations is difficult, then APs should be deployed according to the optimal locations derived from the thinnest covering problem solution in the RORC scenario. However, if APs can be positioned after furniture locations are known, then they should be deployed at the locations provided by the SES algorithm for the multi-AP, multi-obstacle FORC scenario.

In addition, the proposed analytical model and algorithms in this paper can also generate AP placements for non-rectangular rooms, if those rooms are combinations of several rectangular rooms. For example, considering an "L-shaped" room, we can divide it into two rectangular rooms, and generate the optimal (near-optimal) positions of APs for each of them separately.

On the other hand, considering the cost of multiple mmWave AP devices used in indoor scenarios, an alternative is to deploy a single AP and multiple low-cost relays to extend the AP's coverage. In this case, the only additional step is to select an appropriate position for the unique AP among all generated optimal locations. One strategy would be to place the AP at the position with best coverage. For example, in RORC scenarios, we choose the optimal location that has the smallest achievable distance d_{ac}, while in FORC scenarios, the AP could be deployed at the position that is the first one generated by the SES algorithm.

7 CONCLUSION

In this paper, we considered coverage and deployment issues in multi-AP mmWave WLANs. Based on our analytic model, the optimal locations of multiple APs were derived in RORC scenarios, and we showed that deploying up to 5 APs provides the highest performance gains. In the FORC scenario, the shadowing-elimination search algorithm was proposed to determine the placement of APs, and full coverage is achieved with enough APs. Through ns-3 IEEE 802.11ad simulations at 60GHz, the network performance of proposed AP deployments is shown to be always superior to that of other common placement methods. Besides, we also validate that the proposed SES algorithm can generate near-optimal placement of APs, which provides desirable network performance for clients.

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